Impact of Urban Rail Transit on Business Districts Based on Time Distance: Urumqi Light Rail

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Abstract: Based on metacartography, this study establishes a model to convert the time distance of taking light rail to the spatial distance in meters. On this basis, this study uses the spatial transformation method of geographic information system (GIS) map projection to redefine the distance between two locations with the converted distance and transforms the original map into a time distance map. By spatializing the time distance, this study gives time distance a visual expression. The results show that the influence of light rail on urban form is affected by the distance between the station points and the selected center point; that is, that the transformation is greater when the station points are farther away from the center point, and vice versa. The impact of light rail on the layout of business centers is basically distributed in the shape of a circle. Time distance compresses the traditional urban form. There is still much room for the city to further compress the time distance, and the existing business centers should be upgraded. **DOI: 10.1061/(ASCE)UP.1943-5444.0000464.** *This work is made available under the terms of the Creative Commons Attribution 4.0 International license, http://creativecommons.org/licenses/by/4.0/.*

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Introduction

The formation of urban business districts is affected by many factors. According to the theory of commercial location (Brown 1989; Bryan 1990; Cervero 1998), the formation of urban business districts mainly takes on combined impacts from differentiated rent mechanisms, market supply and demand mechanisms, and aggregation and diffusion mechanisms. With different rents in different locations in the city and different orientations of different commercial forms, the differentiated rent mechanism affects the choice of business location. The demand of the consumer market determines the development direction of business districts, and the relationship between supply and demand affects the scale and level of these districts. When one commercial scale expands, different forms of business are generated because commercial space is always in the process of agglomeration or diffusion. The formation of business districts has an inseparable relationship with traffic (Cervero 1992; Hägerstrand 1970). In the early stage of a city, business districts are distributed along the traffic network, land transportation has limited impact on the city's business districts, and the psychological time of consumers has limited impact on their travel frequency and travel distance. Because rail transit has unparalleled advantages compared with other land-based transportation, such as high-speed and large passenger capacity trains, rail transit affects the reformation of business districts (Tiry 2003). According to relevant practical development experience and theoretical research, the influence of rail transit on the evolution of business districts is shown in the three aspects of expected effect, reachability effect, and passenger flow effect.

Traffic plays a role in the formation of business districts, but the development of a city faces many issues, such as the rapid expansion of urban areas, rapid growth of motor vehicles, and urban road congestion. Therefore, traffic is an important problem that affects the quality of residents' lives and must urgently be solved. Urumqi is the political, economic, and cultural center of Xinjiang, the western gateway to the outside world, the bridgehead of the New Eurasian Continental Bridge and the core area of the Silk Road economic zone. Accordingly, Urumqi has seen rapid development in recent years, and urban traffic congestion has gradually increased, with more than 800,000 privately owned cars. The Bus Rapid Transit (BRT) system has completed seven lines and become an important mechanism to meet the public's transportation needs. However, the BRT must occupy dedicated lanes on the ground and thus cannot be considered a long-term solution for urban traffic congestion. According to the observations from cities with subways or light rail, the construction of rail transit has played a significant role in alleviating transport tension, saving transport time, forming economic integration, promoting the development of a knowledge economy, promoting the development of tertiary industries and tourism, providing employment opportunities, and improving the quality of urban residents' lives. The importance of rail transit includes not only freeing up space on the ground, which was originally narrow, but also shortening the time distance between two locations under the premise of unchanged geographical distance. In particular,

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a stable transportation system that is not affected by bad weather greatly improves the travel efficiency of an entire city.

Time geography was put forward for the first time by Hägerstrand in a paper published in 1970 (Hägerstrand 1970), which set up unique geography symbol systems such as path and prism. With the development of computers and geographic information systems (GISs), Lenntorp, Martin, Miller, Kwan, and others constantly improved the calculation method of time geography (Kwan 2004; Kwan and Weber 2003; Lenntorp 1977, 1999; Miller 1991, 2005). Time geography is a new development in transport planning, the family and individual level, the urban activity system, time use and management, environmental and public health, and other fields (Dijst and Vidakovic 1997; Hallin 1991; Neutens et al. 2007, 2011, 2012, Shaw and Yu 2009; Yu 2007). In recent years, Ellegård and others put forward the concept of "new" time geography (Ellegård 1999; Ellegård and Svedin 2012). Liu, Kuby, Hadas, and others studied public transportation from the aspects of connectivity and passenger flow volume (Hadas and Ranjitkar 2012; Kuby et al. 2004; Liu et al. 2016). There are also studies on the cost of transfer in public transport systems (Guo and Wilson 2011). Ferbrache studied the influence of traffic on urban development from the perspective of cultural approaches to transport geography (Ferbrache and Knowles 2017). Hurst, Kasraian, Sekar, and others studied the impact of the rail transit system on land use and land-use change (Hurst and West 2014; Kasraian et al. 2016; Sekar and Gangopadhyay 2017). The analysis concentrated on North America in three main areas: urban development and land values, health and environmental impact, and socioeconomic factors (Knowles and Ferbrache 2016; Topalovic et al. 2012).

The research of time distance in China mainly focuses on the time distance between cities on the meso level. Most of the studies on the time difference inside cities adopt the research method of isochronic circles. For example, Zhu conducted a metacartography study of time distance with the example of the Fuzhou-Shanghai railway passenger transportation system (Zhu et al. 2010). Zhu also selected the main nodes to study traffic time distance inside Fujian Province (Zhu 2011). With the continuous evolution of the internal spatial pattern of cities, many scholars also study the distribution of urban traffic's isochronic circles through time cost. For instance, Zeng, Chen, Zhao, and Huang divided the cities of the Macao Special Administrative Region, Guangzhou, and Shenzhen into time units and selected two-way links between the main nodes and the city center to research the isochronic circles of transport (Chen 2003; Huang 2003; Zeng 2003; Zhao 2003). Throughout the literature on time distance within cities, most scholars have focused on drawing isochronic circles of travel as the single presentation method but have rarely combined it with time distance mapping.

In the following, we use a novel method of calculation to show the effect of the light rail on the time distance within the city. We try to represent the contraction of space distance in an intuitive way. The aims of this study are to provide a reference for commercial location choice in the future and predict for residents' travel. First, a time distance map is produced by space transformation of time distance. Second, we analyze the effect of this contraction on the urban pattern and business circle. Finally, the applicability and limitations of this method are discussed.

Fig. 1. (Color) General plan of the Urumqi light rail.

Planning of the Urumqi Light Rail and Business Districts

Planning of the Urumqi Light Rail

The downtown area of Urumqi is surrounded by mountains to the east, west, and south. The terrain of Urumqi is high in the southeast and low in the northwest. Its urban construction is distributed in a narrow pattern in a north-south direction.

Urumqi Urban Rail Transit plans to build seven lines with a total length of 211.9 km (Leading Group Office of Urumqi Light Rail Construction and Coordination 2013). The recent construction plan intends to implement Line 1, which has a length of 26.5 km and a total of 21 stations, in advance. Line 2 in the first phase has a length of 21.4 km and consists of 16 stations with a total construction length of 44.4 km; the total investment of the project is 31.2 billion RMB. The plan intends to form the basic framework of a rail transit network to meet the recent growing traffic demand and guide and promote the coordinated development of the regional economy. When the basic network structure is formed, rail transit passengers will account for 10–14% of the total public transport passengers in 2020. The first phase of the rail transit construction is Line 1, with a planned total duration of 7.5 years; the planned construction period is from 2012 to 2016, and the trial operation of the entire Line 1 will occur in 2018. The first phase of the civil engineering project of Line 2 began after the completion of the civil engineering project of Line 1, and the planned total duration is 6.5 years; Line 2 should be complete and ready for operation in December 2020. The first phase of the civil engineering project of Line 4 began in early 2016, with a planned total duration of 7 years; Line 4 should be ready for operation at the end of 2020. (Fig. 1).

Planning of the Urumqi Business Districts

The planning of the Urumqi business system mainly includes international business centers (including the Main International Business Centre and the International Business Subcentre), urban business centers, municipal business centers, regional business

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centers (city sub-centers), community-level business centers, and feature business streets. According to the overall urban planning and commerce and trade development orientation of Urumqi (Urumqi Commerce Bureau 2014), Urumqi business will form an overall development pattern of "two cores, nine hearts, sixteen districts, multiple streets and multiple points."

Two cores: the cores of urban business development are constituted by the Main International Business Centre and the International Business Subcentre and mainly encompass Xinjiang, the entire country, and central and western Asia. Nine hearts: the nine business clusters consist of two urban centers and seven municipal business centers that mainly serve the city of Urumqi and the surrounding areas. The two urban business centers are the Exhibition Business Centre and the High-Speed Rail Business Centre; the seven municipal business centers are the Nanhu Business Centre, the Hongshan Business Centre, the Railway Bureau Business Centre, the South Railway Station Business Centre, the Gumudi Business Centre, the North New District Business Centre, and the South Business Centre. The "two cores" and "nine hearts"—a total of 11 business districts—are included within the scope of this research paper.

Sixteen districts: the 16 business cluster areas that involve regional business centers mainly meet regional residents' demand for the goods that they consume. Multiple streets: by exploring culture and folk resources and emphasizing these characteristics, 33 business streets are formed to lead in a modern business fashion. Multiple points: in focusing on community-level business centers, business cluster areas are formed according to residence and population distribution to meet community residents' demand for the goods that they consume. The "16 districts," "multiple streets," and "multiple points" are business outlets that meet the needs of regional and community residents; because of their small range of application, they are not included within the scope of this research paper (Fig. 2).

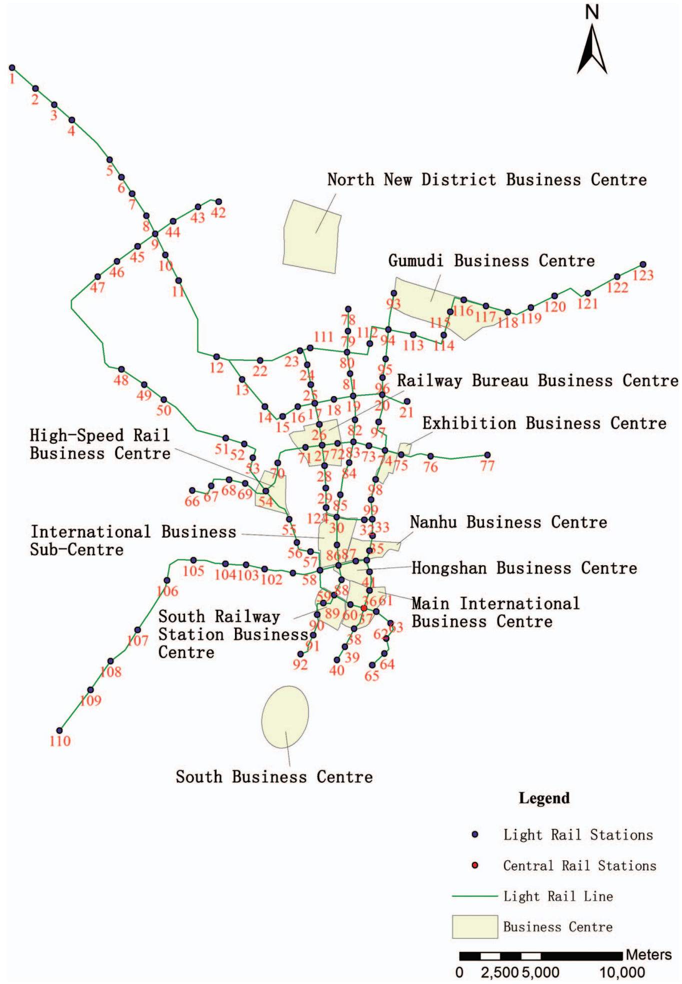

Fig. 2. (Color) Sketch map of the Urumqi light rail stations, light rail line and business center.

Research Methods and Data Sources

Research Methods

This study's research method is based on the basic idea of metacartography (Lenntorp 1999). In 1953, Hägerstrand, from the Department of Geography of Lund University in Sweden, first proposed the term metacartography (Chai 1998; Hägerstrand 1974, 1975, 1982, 1985).

Based on metacartography, this study adopts the space transformation of time distance to build a model to convert the time distance of light rail rides into the spatial distance in meters. Through the space transformation method of GIS map projection, we use the converted spatial distance to redefine the distance between two locations and transform the original map into a time distance map. Based on this time distance map, we visualize on the map the spatial compression that is caused by the intracity traffic time compression (Kwan 2012; Tobler 1961).

Data Sources

In this paper, the city center is defined as the time from the center of South Gate to various end points. South Gate is the old city center of Urumqi and is located in the main international business district—in one of the "two hearts." South Gate is a landmark site of Urumqi, and the autonomous regional government is distributed near it. Since ancient times, South Gate has been Urumqi's commercial, cultural, and financial center; thus, South Gate is selected as the compression center of this study. As early as the 1920s, the Nanguan area south of South Gate formed a business street, and the Shidazi area in the north not far from South Gate was the business center of Urumqi. There were human markets, horse markets, day markets, night markets, shops of merchants of various nationalities, and trading companies of Russian merchants. Since the reform and opening up, especially recently, the business district of South Gate has been further expanded. In 2003, the International Bazaar began to operate, and it became Urumqi's business and tourism center with increasingly more guests from around the world. The number of visitors reached 671,000 in July 2016, with a daily number of more than 33,000 people who arrived mainly on public transport (Zang 2016). It is difficult to park a car and obtain car rides near the International Bazaar, and traffic congestion is very severe, which to some extent affects tourists' choice of transportation to the International Bazaar (Erbıyık et al. 2012).

The design speed of light rail is 80 km/h. However, considering the acceleration and deceleration between stations, the actual travel speed is lower than the design speed. The performance and standards of subways and lines in the metro cities in China, such as Shanghai, Beijing, Nanjing, Shenzhen, and Hangzhou, are a maximum speed in operation of 80 km/h and an average speed of generally 30–40 km/h. Therefore, this paper uses 40 km/h when calculating the speed of light rail and assumes that the average time length of a stop at each station is 40 s (Huaxia Latitude Network 2012).

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This paper's light rail plan originates from the Urumqi Rail Office (Urumqi City Rail Group). The research area includes the downtown region of Urumqi, with an area of 1,435 km^2. The downtown area comprises the eight functional areas of the Tianshan District, Shayibak District, Hi-tech District (New Urban Area), Shuimogou District, Midong District, Economic Development District (Toutunhe District), and North New District. In the north, the downtown area borders Wuyi Farm, Anningqu Township, Gumudi Township, and the Lucaogou Township administrative boundary. In the south, the downtown area borders the administrative boundary of the Tianshan District. In the east and west, the downtown area borders the outer ring of the planned highway. The downtown area also includes the section of Changji City (which is located northwest of Urumqi) that is covered by light rail.

Results

Time Distance Calculation and Conversion

According to a formula, we calculate the time distance from South Gate to the end of each line (time to arrive at destination) (Table 1).The time and distance reserves two decimal fractions while computing.

To give the space compression of time distance a more intuitive expression in the map, we use the actual speed of a city car, 20 km/h, as the reference speed. To compare time distance and actual space distance, we convert the time to arrive at a station to the time distance in meters. The calculation method is (Yu et al. 2013)

$$DT_i = DS_0 \times \frac{T_i}{T_0} \quad (i = 1, 2, 3 \ldots, n) \tag{1}$$

where DS_0 = car-driving distance between two locations in the city; and T_0 = average required time for DS_0. Therefore, DS_0/T_0 is the actual car speed in the city. After conducting on-site tests with taxis at different times in the city, we set this value at 20 km/h. DT_i is the space conversion result of the time distance from South Gate to each destination, and T_i is the time from South Gate to each station. To more intuitively show the trend of the narrowing time distance of intracity traffic after the completion of the light rail and to reasonably compare time distance with space distance, we calculate the time distance between the South Gate station and each station after the formation of all light rail lines according to the formula (Table 1).

Time Distance Map Making

We use locations i and j as examples. The geographical coordinates of the two locations are (x_i, y_i) and (x_j, y_j), respectively. The time distance that is formed by a given traffic pattern is T_{ij}, and the space conversion result of the time distance is DT_{ij}. The mathematical process for the visualized expression is as follow (Yu et al. 2013).

The vector is

$$\mathbf{a}_{ij} = (x_j - x_i, y_j - y_i) \tag{2}$$

The direction vector is

$$\mathbf{e}_{ij} = \left(\frac{x_j - x_i}{\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}}, \frac{y_j - y_i}{\sqrt{(x_j - x_i)^2 + (y_j - y_i)^2}} \right)$$

With i as a starting point, $\mathbf{e}_{ij}$ as the direction vector, and the norm of the vector as DT_{ij}, we can determine the time distance $j'(x_j', y_j')$ from location j to the actual location i. The line segment between i and j' in the map is the time distance between the two points.

The previous step forms the corresponding relationship of j and j'. Now we can use the Rubbersheet method of the ArcGIS software to stretch the map layers with j as the starting point and j' as the ending point. By repeating the previous operation, we obtain a time distance map (Figs. 3 and 4). In Fig. 3, the starting points of the vectors on the original light rail sites and the end of vectors to the displacement of position are shown.

Analysis of the Spatial Transformation Results of the Time Distance

Overall, the time and the spatial distance maps have varying degrees of compression. Northwest of the central point and Lines 3 and 7 in the north of the city have a greater degree of and more obvious compression. The terminal stations of Lines 1–3 in the south are Santunbei, the Border Control Bureau, and No. 12 Middle School. Northeast and southeast of the research scope have a smaller degree of and less obvious compression. Several business districts have changed location and shape. It is worth noting that because stations are selected as only the center of gravity during the mapping process, namely, that the "surface" is converted to a "point," this time map can represent only the characteristics of space-time compression, not all the points' actual time distance.

Discussion: Analysis of the Influence of Light Rail on the Urban Structure and Business Districts

Based on the time distance map and Urumqi's business districts, this paper analyzes the light rail's influence on the study area after its completion.

Analysis of the Light Rail Stations

The actual distance between each station and the center point is D_i, and the converted time distance of each station is DT_i. This paper establishes the relationships among D_i, DT_i, D_i, and $D_i - DT_i$ and conducts linear fitting. The relationship between D_i and DT_i is $y = 0.6768x$ (Fig. 5). We find that with an increase in the distance from the stations, DT_i shows a significant linear increase, which indicates that the stations that are closer to the center still have a traffic advantage, but not all DT_i increases with an increase of D_i. Some individual stations improve traffic accessibility with the light rail. The relationship between D_i and $D_i - DT_i$ is $y = 0.3232x$ (Fig. 6). With an increase in the distance from the stations, $D_i - DT_i$ also shows a significant linear increase, which indicates that the light railway plays a more obvious role when improving the traffic accessibility of the stations that are far away from the center, but we cannot rule out the more obvious advantages of some points. $(D_i - DT_i)/D_i$ is the compression ratio. This ratio fluctuates and compresses approximately 35% in the end (Fig. 7), which shows that the compression degree of the time distance has no obvious linear relationship with the actual distance but reaches a stable value in the end.

This result occurs because some stations are affected by the number of transfer stations and can only be reached after two transfers, and some stations can only be reached after multiple stops, which requires more time than driving cars, and the time that is saved by the light rail is offset. However, the light rail has the advantage of not being affected by bad weather, traffic jams, parking

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Table 1. Time required to arrive at each station from South Gate

Number	Station	Distance from South Gate (m)	Number of stations in between	Time of transfer	Time to arrive at destination (min)	Space conversion of time distance
1	Changjixi	45,347.02	28	1	89.69	29,895.73
2	Zhongshan Road	43,501.84	27	1	86.25	28,750.92
3	Changji	42,020.37	26	1	83.36	27,787.96
4	Lvzhou Road	40,631.76	25	1	80.61	26,871.43
5	Wuyiwulian	37,342.91	24	1	75.01	25,004.79
6	Wuyijiulian	36,104.44	23	1	72.49	24,163.33
7	Sanpingsanlian	34,926.47	22	1	70.06	23,352.12
8	Zhengda Husbandry	33,368.18	21	1	67.05	22,350.76
9	Sanping New District	32,165.63	20	1	64.58	21,527.26
10	Xijiao Electric Power Bureau	30,765.64	19	1	61.82	20,605.04
11	Tiancai Science Park	29,048.69	18	1	58.57	19,524.35
12	Airport	23,396.58	17	0	46.43	15,476.07
13	Jiuyunsi	20,543.90	16	1	44.48	14,827.50
14	No. 5 Middle School of Railway Bureau	18,428.05	15	1	40.64	13,547.36
15	Hebin Residential Area	17,001.54	14	1	37.84	12,611.88
16	Municipal Administrative College	15,911.12	13	1	35.53	11,844.45
17	Botanical Garden	14,884.26	12	0	30.33	10,108.80
18	Normal University for Nationalities	16,055.37	13	1	35.75	11,916.57
19	Liangxiao	14,062.97	10	1	30.76	10,253.71
20	Xinjiang Normal University	13,390.37	9	1	29.09	9,695.19
21	Division of Motor Vehicles	14,961.68	10	2	35.11	11,703.06
22	Diwopudong	20,754.89	16	0	41.80	13,933.00
23	Xuanrendun	18,250.36	15	0	37.38	12,458.51
24	Bureau of Reclamation	17,236.05	14	0	35.19	11,729.14
25	Machinery Plant	16,021.70	13	0	32.70	10,899.74
26	Sports Centre	13,605.94	11	0	27.74	9,247.42
27	Railway Bureau	12,341.62	10	0	25.18	8,393.03
28	Xiaoxigou	11,111.14	9	0	22.67	7,555.57
29	Dazhaigou	9,790.06	8	0	20.02	6,672.81
30	Balou	7,586.51	6	0	15.38	5,126.59
31	Wangjiaqu	5,938.91	5	0	12.24	4,080.57
32	Hualian Vocational School	5,461.63	4	0	10.86	3,619.70
33	China Mobile	4,482.09	3	0	8.72	2,907.71
34	Nanhu Plaza	3,561.13	2	0	6.68	2,225.01
35	1-7 Transfer	2,981.36	2	0	5.81	1,935.13
36	North Gate	1,101.08	0	0	1.65	550.54
37	South Gate	0.00		0	0.00	0.00
38	Erdaoqiao	1,349.71	0	0	2.02	674.85
39	Xinjiang University	2,590.23	1	0	4.55	1,517.34
40	Santunbei	3,500.12	2	0	6.58	2,194.51
41	Xinxing Street	2,268.64	1	0	4.07	1,356.54
42	Wuyishilian	38,945.47	19	0	71.08	23,694.96
43	Majiangzhuang	37,605.05	18	0	68.41	22,802.52
44	Wuyisilian	35,875.81	17	0	65.15	21,715.68
45	Sanpingbalian	33,296.71	15	0	59.95	19,981.69
46	Sanpingqingnianlian	31,784.28	14	0	57.01	19,003.25
47	Sanpingwulian	30,310.07	13	0	54.13	18,043.92
48	Wangjiagou	22,659.05	12	0	41.99	13,996.19
49	West Railway Station	21,012.04	11	0	38.85	12,950.47
50	Henanzhuang	19,549.93	10	0	35.99	11,997.19
51	Mianma	15,059.85	9	0	28.59	9,529.93
52	Mianmadong	13,897.43	8	0	26.18	8,726.49
53	Huashan Street	12,641.54	7	0	23.63	7,876.33
54	Ergong (2-4 Transfers)	10,307.52	6	0	19.46	6,487.09
55	Jiujiawan	8,054.88	5	0	15.42	5,138.55
56	Agricultural University	6,597.19	4	0	12.56	4,187.48
57	Old Man City	5,444.27	3	0	10.17	3,388.80
58	Nanchang Residential Area	3,911.72	2	0	7.20	2,400.31
59	Nianzigou	1,951.87	1	0	3.59	1,198.16
60	Lijiaoqiao	839.74	0	0	1.26	419.87
61	Autonomous Regional Government	758.77	0	0	1.14	379.39
62	School of Education	1,096.79	1	0	2.31	770.62

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Table 1. (*Continued.*)

Number	Station	Distance from South Gate (m)	Number of stations in between	Time of transfer	Time to arrive at destination (min)	Space conversion of time distance
63	Erdaowan	2,184.33	2	0	4.61	1,536.61
64	Dawan	3,203.04	3	0	6.80	2,268.19
65	Border Control Department	4,218.20	4	0	8.99	2,997.99
66	Dairy Farm	15,608.37	10	1	33.08	11,026.41
67	Hengyi Road	14,141.59	9	1	30.21	10,070.79
68	Weiliu Road	12,796.33	8	1	27.53	9,175.94
69	Ergong Tower	11,813.64	7	1	25.39	8,462.38
70	Cotton Textile Warehouse	12,249.07	12	1	29.37	9,791.20
71	Railway Hospital	14,413.34	11	1	31.95	10,651.12
72	Tianran Si	13,288.60	11	1	30.27	10,088.75
73	Automobile City	10,753.16	8	2	27.46	9,154.36
74	Bajiahu	9,739.37	7	1	22.28	7,425.24
75	Exhibition Centre	10,531.89	8	1	24.13	8,043.72
76	Qidaowan	12,360.58	9	1	27.54	91,80.29
77	Lucaogou	15,775.69	10	1	33.33	11,110.07
78	Linchang	19,314.32	14	1	41.30	13,768.27
79	Fuel Depot	18,014.94	13	1	38.69	12,896.36
80	Sangongbei	16,683.26	12	1	36.02	12,008.29
81	Sangongnan	15,401.25	11	1	33.44	11,145.07
82	Tuanjie Residential Area	12,631.19	9	1	27.95	9,315.60
83	Gas Plant	11,306.72	8	1	25.29	8,431.14
84	Logistics Zone	10,047.39	7	1	22.74	7,579.25
85	Liyushan	8,041.84	6	1	19.06	6,354.25
86	Friendly Shopping Mall	5,046.50	4	1	13.24	4,412.14
87	Foreign Trading Company	3,811.94	3	1	10.72	3,572.64
88	Postal Office	2,975.36	2	1	8.80	2,932.12
89	Medicine Company	2,925.68	2	1	8.72	2,907.28
90	South Railway Station	3,899.71	3	1	10.85	3,616.52
91	Huochang	5,181.67	4	1	13.44	4,479.72
92	No. 12 Middle School	6,660.99	5	1	16.32	5,441.60
93	Shangshahexi	19,492.80	13	1	40.91	13,635.29
94	Xinjiang Wujian	17,291.06	12	1	36.94	12,312.20
95	Sewage Plant	15,540.00	11	1	33.64	11,214.44
96	East Railway Station	14,415.37	10	1	31.29	10,429.91
97	Shisanjian	11,738.95	8	1	25.94	8,647.25
98	Baiwanzhuang	7,867.36	6	1	18.80	6,267.01
99	Yihaolijin	6,633.11	5	1	16.28	5,427.67
100	Erlianban	3,674.84	3	1	10.51	3,504.09
101	Maliaodi	5,541.80	3	1	13.31	4,437.56
102	Xishan Street	7,276.95	4	1	16.58	5,527.36
103	104 Tuan	8,401.21	5	1	18.94	6,311.72
104	Sidaocha	9,646.78	6	1	21.47	7,156.72
105	Xishanqiaoxi	11,563.08	7	1	25.01	8,337.09
106	Xishanqiaonan	14,015.69	8	1	29.36	9,785.62
107	Niumaohubei	17,476.02	9	1	35.21	11,738.01
108	Niumaohunan	19,963.25	10	1	39.61	13,203.85
109	Xishan	22,068.86	11	1	43.44	14,478.88
110	Xishannan	25,095.54	12	1	48.64	16,214.44
111	Zhongmiaochang	18,897.98	13	2	43.01	14,337.88
112	Guangai Chang	18,615.43	13	2	42.59	14,196.61
113	North Sewage Plant	18,794.77	13	2	42.86	14,286.27
114	Traffic School	21,113.71	14	2	47.00	15,667.97
115	Shangshahe	22,539.89	15	2	49.81	16,603.28
116	Gumudi	24,009.82	16	2	52.68	17,560.47
117	Gumudidong	25,403.69	17	2	55.44	18,479.62
118	Dongshan	25,403.69	18	2	56.11	18,701.84
119	Zhenxing Street	28,237.00	19	2	61.02	20,340.72
120	Tiechanggouxi	29,818.42	20	2	64.06	21,353.66
121	Tiechanggoudong	32,126.33	21	2	68.19	22,729.83
122	Midongshihua	34,142.98	22	2	71.88	23,960.38
123	Midongshihuabei	35,842.09	23	2	75.10	25,032.16
124	Daxigou	8,609.96	7	0	17.58	5,860.54

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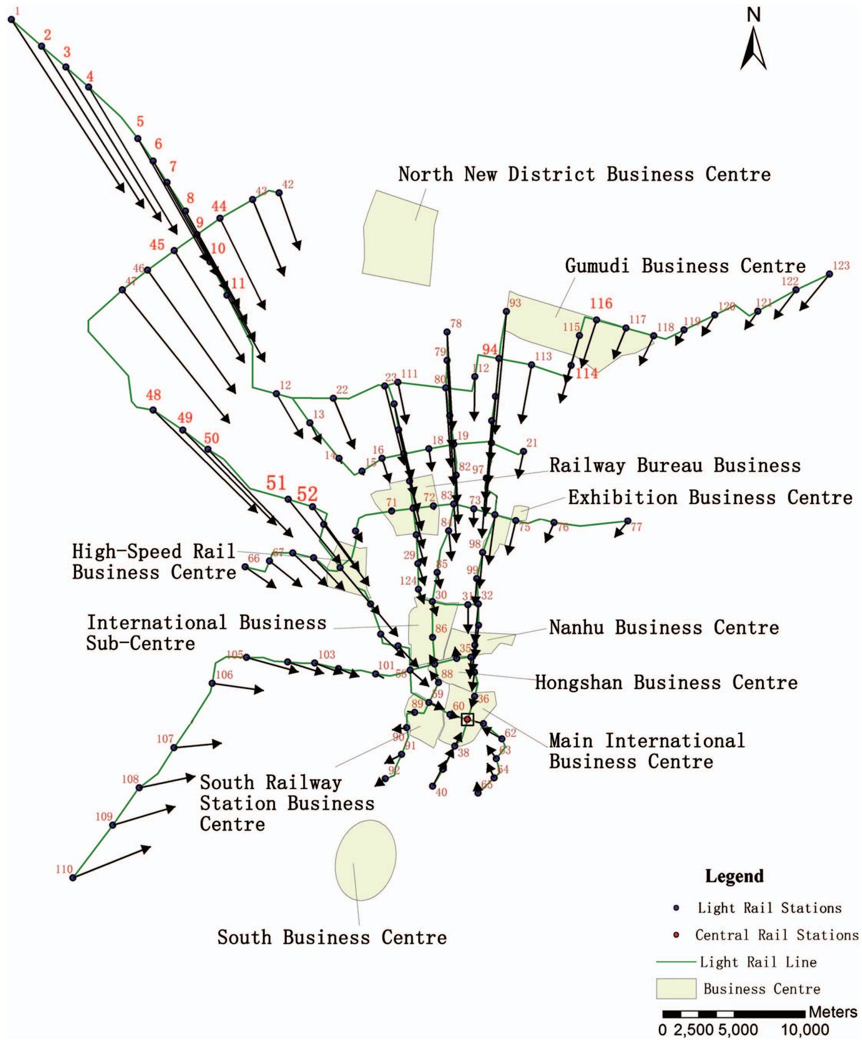

Fig. 3. (Color) Light rail time distance map (before shrink).

problems, and other uncontrollable factors. Thus, the comparison here is only relative and does not mean that the traffic around these sites is deteriorating.

Analysis of the Influence and Regularity of the Business District Pattern

The existing pattern of business district distribution is the point-axis distribution along the roads. Traffic nodes tend to form large business centers and spread out from the center point in circle layers.

We use the hierarchical cluster method of SPSS software (Fig. S1). The stations are divided into six levels based on the compression distance (Table 2). The International Main Business Centre, the International Business Sub-Centre, the Hongshan Business Centre, the Railway Station Business Centre, and Nanhu Business Centre are located in the traditional business district. The Exhibition Business Centre, Railway Bureau Business Centre, and High Speed Rail Business Centre are on the second level, and Gumudi Business Centre is on the third level. There are no business centers in the fourth and fifth levels. Because of the integration of Urumqi and Changji City, Changji is also planned to connect to Urumqi through light rail in the future (Leading Group Office of Urumqi Light Rail Construction and Coordination 2013). As a result, Changji is treated as a special business center and is on the sixth level. The distribution of traditional business districts spreads out according to the shape of the traffic roads. The leveled distribution of new business districts is basically consistent with the leveled distribution of land transportation methods. However, certain individual stations are bypassed. These stations are located on the edge of business centers or are on the borderlines of multiple business centers, which pull on the business districts that they belong to. Some business districts extend to or overlap with the business districts at a higher or lower level, which causes internal division (e.g., the Exhibition Business Centre and the International Business Subcentre). The formed subdistrict becomes another core of this business center or a new business center itself (Fig. 8).

The survey data show that within urban areas, the average travel time with a bus is 31 min, with a car is 27 min, and on foot is 20 min. In the current situation, the travel distance of most residents is approximately 4–5 km and is considered short-range travel (Information Technology Co. Ltd. 2015). After the completion of the light rail, the time distance will shorten, which will expand the scope of residents' activities and affect residents' decision-making regarding travel. Time distance will replace the traditional travel distance to become the new standard to measure residents' travel. Leaving a residence to shop in distant business districts will be less dependent on land traffic congestion, but the distance will be calculated with the number of "stations." The central business districts

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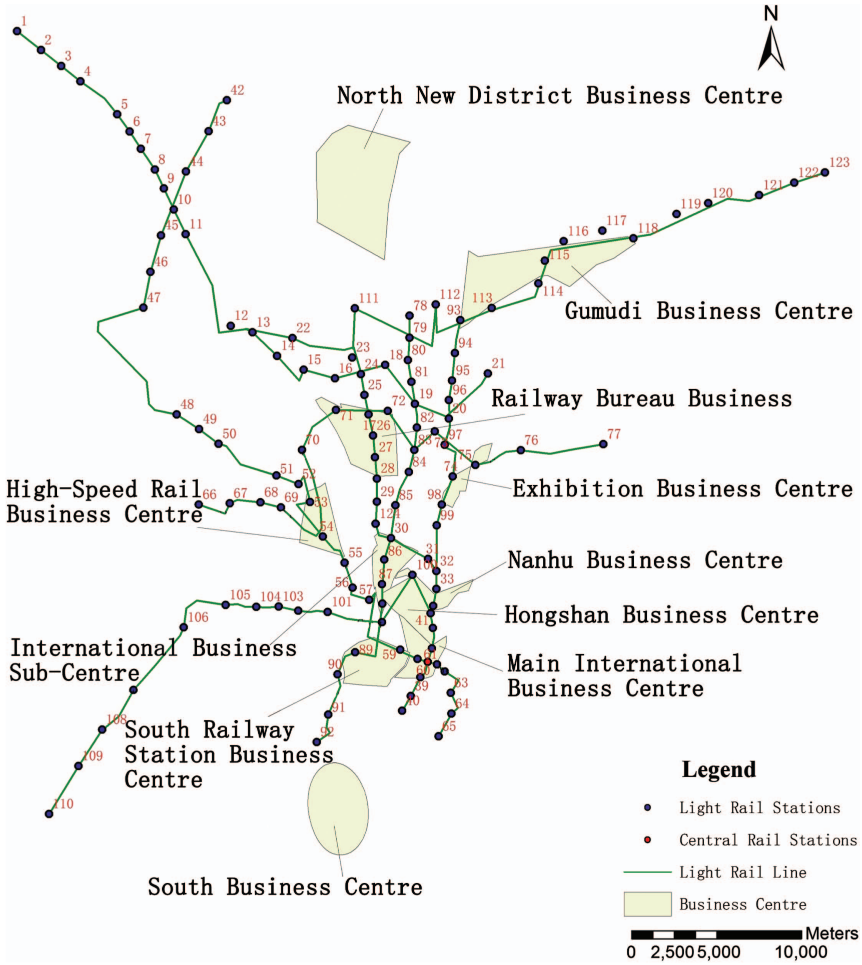

Fig. 4. (Color) Light rail time distance map.

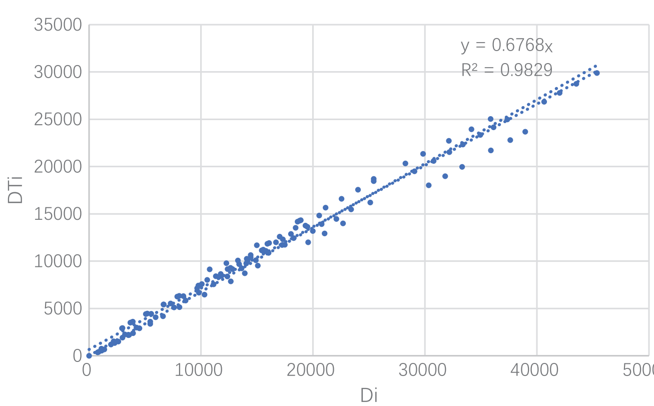

Fig. 5. (Color) Relation between D_i and DT_i.

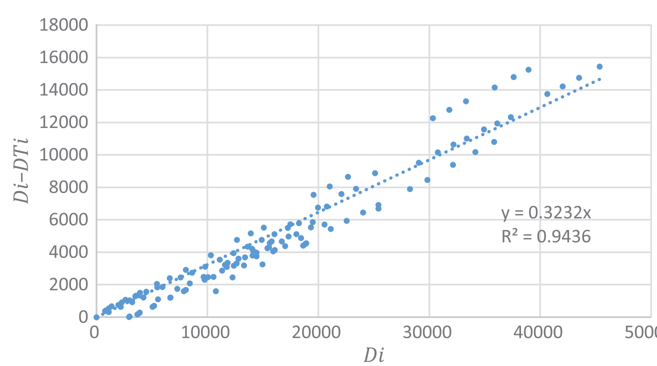

Fig. 6. (Color) Relation between D_i and $D_i - DT_i$.

will be further strengthened, and new business districts will be more easily developed in the areas with a greater compression of the time distance.

The areas around transfer stations are more conducive to the formation of business centers. By investigating several business centers, we find that the light rail stations are undoubtedly located at these business centers or on the edge of them or are crossovers that form transfer stations; transfer stations enhance the flow of people at these business centers and promote the improvement of business districts. Areas with intensive transfer stations are more likely to form large business centers. Combined with the level of compression, we analyze and predict that the areas that are near certain stations will form potential business centers in the future as follows.

No. 12 Station is located at the airport, which is between Urumqi and Changji. A near-port business center will be created here to develop a near-port business district. Stations No. 23, 80, 112, 17, 19, and 20 are located north of the city to serve the population and the functional transfer of the old city. Large residential areas will be formed here in the future, and if the government relocates these areas, the development of business districts will be further promoted.

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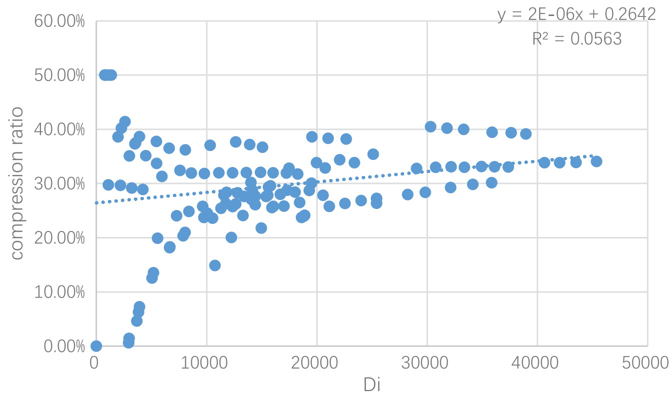

Fig. 7. (Color) Relation between D_i and compression ratio.

Influence of the Urban Spatial Layout and a Countermeasure Analysis

In the entire research area, the north, northwest, and east of the city demonstrate more obvious compression, whereas the south is not compressed, which is consistent with the recent urban planning concept of Urumqi, namely to "connect in the east, deepen in the west, control in the south and expand in the north." The business centers in the downtown area still have unparalleled regional advantages; however, convenient transportation increases the competition among business districts. The main business districts in Changji will compete with the Urumqi city area after the light rail transformation, which will shorten the distance between the two cities and is consistent with the regional policy of "integrating Urumqi and Changji." The South Business Centre in the south of the city is building a maglev to connect to the downtown area. This maglev will greatly enhance the connection between the southern region and the downtown area. The North New District Business Centre in the north of the city does not have light rail stations; bus connection to the closest light rail stations should be added and increased in this area, and light rail planning in later planning stages should increase the extension of nearby lines.

Research with time distance mapping provides a new way of thinking of business district analysis. Time distance mapping can verify the existing business districts or the business districts with future development potential and predict the locations of new future business districts. From the time distance map of Urumqi, we can tell that the areas along the light rail will become an important direction of urban expansion because they provide new space for urban development. Consequently, the pattern of Urumqi urban land use will be changed; the formation and development of new business cores, residential spaces, and industrial agglomeration areas will affect the space layout, development strength, and economic efficiency of the entire city's land use.

Convenient light rail transpiration improves the exchange of information between the areas along the rail lines and the downtown area. The construction of light rail will have an impact on how urban residents perceive space. Behavioral geography's study on spatial perception does not replace the analysis of land use's functional and social aspects, but it provides another interpretation of the relationship between man and his environment; it supplements the analysis of urban land use's functional and social aspects (Xu et al. 2009). Because the impact of various behavior constraints changes the output of the impression structure, the completion of light rail will have a structural impact on residents' travel time

Table 2. The stations are divided into five levels based on the compression distance

Number	Station	Compression district	Business districts it belongs to	Compression level classification
1	Jichangxi	15,451.29	Changji City	6th
42	Wuyishilian	15,250.51	—	
43	Majiazhuang	14,802.52	—	
2	Zhongshan Road	14,750.92	Changji City	
3	Changji	14,232.41	Changji City	
44	Wuyisilian	14,160.13	—	
4	Lvzhou Road	13,760.32	Changji City	
45	Sanpingbalian	13,315.02	—	
46	Sanpingqingnianlian	12,781.03	—	
5	Wuyiwulian	12,338.12	—	5th
47	Sanpingwulian	12,266.15	—	
6	Wuyijiulian	11,941.11	—	
7	Sanpingsanlian	11,574.34	—	
8	Zhengda Husbandry	11,017.43	—	
123	Midongshihuabei	10,809.94	—	
9	Sanping New District	10,638.37	—	
122	Midongshihua	10,182.60	—	
10	Xijiao Electric Power Bureau	10,160.60	—	
11	Tiancai Science Park	9,524.35	—	4th
121	Tiechanggoudong	9,396.50	—	
110	Xishannan	8,881.10	—	
48	Wangjiagou	8,662.86	—	
120	Tiechanggouxi	8,464.77	—	
49	West Railway Station	8,061.58	—	
12	Airport	7,920.51	—	
119	Zhenxing Street	7,896.28	—	
109	Xishan	7,589.99	—	
50	Henanzhuang	7,552.74	—	

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Table 2. (*Continued.*)

Number	Station	Compression district	Business districts it belongs to	Compression level classification
117	Gumudidong	6,924.07	Gumudi Business Centre	3rd
22	Diwopudong	6,821.89	—	
108	Niumaohunan	6,759.40	—	
118	Dongshan	6,701.84	—	
116	Gumudi	6,449.36	Gumudi Business Centre	
115	Shangshahe	5,936.61	Gumudi Business Centre	
93	Shangshahexi	5,857.51	—	
23	Xuanrendun	5,791.85	—	
107	Niumaohubei	5,738.01	—	
13	Jiuyunsi	5,716.39	—	
78	Lichang	5,546.05	—	
51	Mianma	5,529.93	—	2nd
24	Bureau of Reclamation	5,506.91	—	
114	Jiaotong School	5,445.74	—	
52	Mianmadong	5,170.94	—	
25	Machinery Plant	5,121.96	—	
79	Fuel Depot	5,118.58	—	
94	Xinjiang Wujian	4,978.87	—	
14	No. 5 Middle School of Railway Bureau	4,880.69	—	
17	Botanical Garden	4,775.46	—	
53	Huashan Street	4,765.22	—	
80	Sangongbei	4,674.96	—	
77	Lucaogou	4,665.62	—	
66	Dairy Farm	4,581.96	—	
111	Zhongmiaochang	4,560.10	—	
113	North Sewage Plant	4,508.50	—	
112	Guangai Chang	4,418.83	—	
15	Hebin Residential Area	4,389.66	—	
26	Sports Centre	4,358.53	Railway Bureau Business Centre	
95	Sewage Plant	4,325.55	—	
81	Sangongnan	4,256.18	—	
106	Xishanqiaonan	4,230.07	—	
18	Normal University for Nationalities	41,38.79	—	
67	Hengyi Road	4,070.79	—	
16	Municipal Administrative College	4,066.67	—	
96	East Railway Station	3,985.46	—	
27	Railway Bureau	3,948.59	Railway Bureau Business Centre	
54	Ergong (2-4 Transfer)	3,820.42	High-Speed Rail Business Centre	
19	Liangxiao	3,809.26	—	
71	Railway Hospital	3,762.23	Railway Bureau Business Centre	
20	Xinjiang Normal University	3,695.19	—	
68	Weiliu Road	3,620.39	—	
28	Xiaoxigou	3,555.57	Railway Bureau Business Centre	
69	Ergong Tower	3,351.27	—	
82	Tuanjie Residential Area	3,315.60	—	
21	Division of Motor Vehicles	3,258.62	—	
105	Xishanqiaoxi	3,225.98	—	
72	Tianran Si	3,199.86	Railway Bureau Business Centre	
76	Qidaowan	3,180.29	—	
29	Dazhaigou	3,117.25	—	
97	Shisanjian	3,091.70	—	
55	Jiujiawan	2,916.33	—	
83	Gas Plant	2,875.58	—	
124	Daxigou	2,749.42	—	
104	Sidaocha	2,490.06	—	
75	Exhibition Centre	2,488.17	Exhibition Business Centre	
84	Logistics Zone	2,468.14	—	
30	Balou	2,459.92	International Business Sub-Centre	
70	Cotton Textile Warehouse	2,457.87	—	
56	Agricultural University	2,409.71	—	
74	Bajiahu	2,314.13	Exhibition Business Centre	
103	104 Tuan	2,089.50	—	
57	Old Man City	2,055.47	—	

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Table 2. (*Continued.*)

Number	Station	Compression district	Business districts it belongs to	Compression level classification
31	Wangjiaqu	1,858.35	—	1st
32	Hualian Vocational School	1,841.93	—	
102	Xishan Street	1,749.59	—	
85	Liyushan	1,687.59	—	
98	Baiwanzhuang	1,600.35	Exhibition Business Centre	
73	Automobile City	1,598.80	—	
33	China Mobile	1,574.38	—	
58	Nanchang Residential Area	1,511.42	—	
34	Nanhu Plaza	1,336.12	Nanhu Business Centre	
40	Santunbei	1,305.62	—	
65	Border Control Department	1,220.21	—	
92	No. 12 Middle School	1,219.38	—	
99	Yihaolijin	1,205.44	—	
101	Maliaodi	1,104.23	—	
39	Xinjiang University	1,072.89	—	
35	1-7 Transfer	1,046.24	Hongshan Business Centre/Nanhu Business Centre	
64	Dawan	934.85	—	
41	Xinxing Street	912.10	Hongshan Business Centre	
59	Nianzigou	753.71	Train Station Business Centre	
91	Huochang	701.95	—	
38	Erdaoqiao	674.85	The Main International Business Centre	
63	Erdaowan	647.72	—	
86	Friendly Shopping Mall	634.36	International Business Sub-Centre	
36	North Gate	550.54	Main International Business Centre	
60	Lijiaoqiao	419.87	Main International Business Centre	
61	Autonomous Regional Government	379.39	Main International Business Centre	
62	School of Education	326.17	—	
90	South Railway Station	283.19	Train Station Business Centre	
87	Foreign Trading Company	239.30	Hongshan Business Centre	
100	Erlianban	170.75	Hongshan Business Centre	
88	Postal Office	43.24	Hongshan Business Centre	
89	Medicine Company	18.39	Train Station Business Centre	
37	South Gate	0.00	Main International Business Centre	

perception; light rail will expand residents' activity space, increase their travel frequency, and shorten the travel time distance in terms of their intended space.

Conclusions

This study is illustrated by the example of Urumqi, and also has reference significance for the other cities that are building light rail.

Between different levels of business districts: (1) Business districts are centered in the downtown area and distributed in circular shapes. The central business districts will be strengthened. Downtown business districts still have a regional advantage; considering competition, they should upgrade their service industries and develop different forms of business in combination with light rail stations, such as underground shops. (2) The districts on the edge will produce a centripetal force because of a shortened time distance. Light rail construction will greatly promote the development of business districts on the edge of business districts; these areas should improve their internal service industries to attract passengers.

Micro level within the specific business districts: (1) Some business districts will encroach on adjacent business districts, and business districts will have internal differentiation. (2) New traffic nodes will form around transfer stations, the flow of people will increase, and the original business center layout will demonstrate micro changes. (3) Business centers that do not have light rail access should strengthen their connection with the surrounding bus stations to compensate for their traffic disadvantages.

This study has several limitations. First, because the research scale covers the city and surrounding area, some areas' time and spatial distances do not show obvious compression on this scale. Second, in the time distance mapping, the selected stations represent a certain area, but the number of sample "points" depends on the light rail stations. The obtained time distance map can only represent time and space compression, not the actual time distance of all points. Third, this study selects the South Gate station in the old city as the center point of compression; the new city planning proposes the building of double centers. If the research is continued, it can select a second compression point to observe the influence of the railway transportation business center. Fourth, because this study targets the time-space compression that light rail causes on urban traffic, it does not conduct an in-depth study on other transportation methods and the areas without light rail access. Fifth, this article is based on group research. Kwan et al. developed a geographical narration method based on GIS in the application of spatial and temporal behavior research, which took a behavior main body as its object to analyze its daily travel behavior. It fused qualitative analysis such as social culture and subjectivity (Kwan 2008, 2013; Kwan and Ding 2008; Kwan et al. 2015). With the progression of the Urumqi subway construction process and the improvement of infrastructure, there is still much room for the

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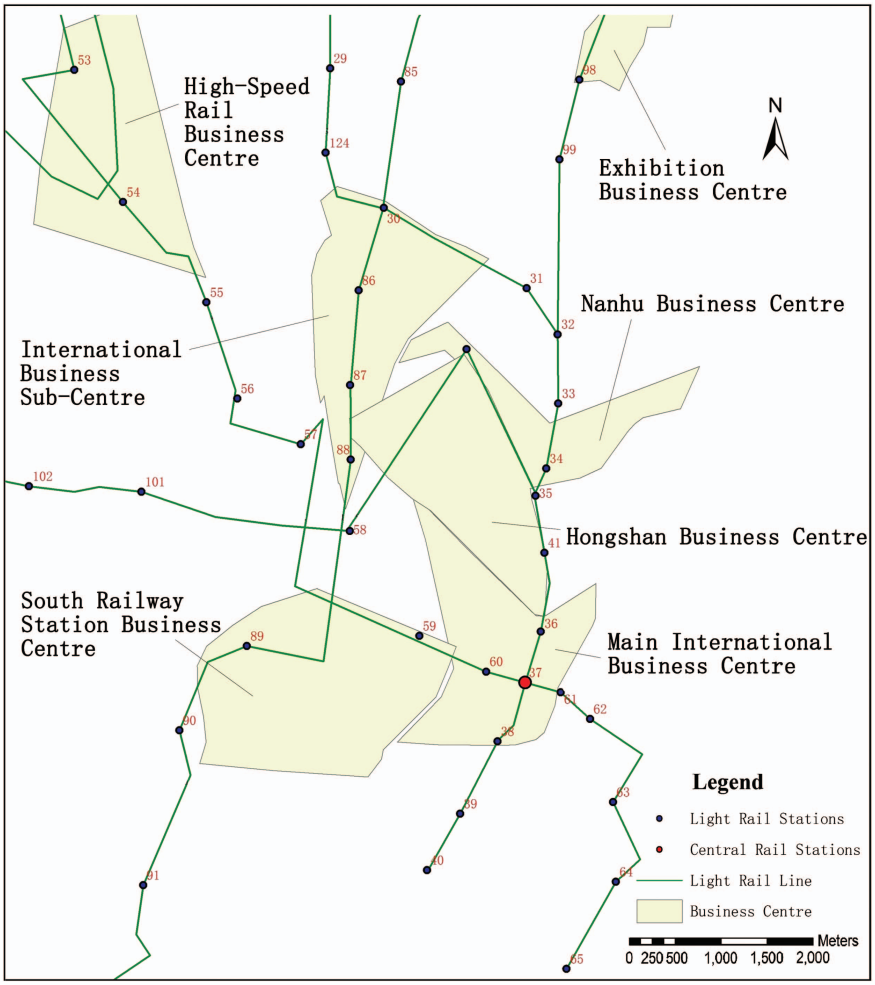

Fig. 8. (Color) Local contraction.

further compression of time distance within the city. More feature differentiation with "space distance" will appear; the distribution of the urban population and business districts will also demonstrate new characteristics. We hope that these new features will attract further attention and research commitment from more geographers.

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Supplemental Data

Fig. S1 is available online in the ASCE Library (www.ascelibrary.org).

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